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RECLAMATION OF RE-USABLE WATER FROM SEWAGE

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PROGRESS REPORT

RECLAMATION OF RE-USABLE WATER FROM SEWAGE

DEMONSTRATION PROJECT GRANT

NO. WPD-21-01

Dr. Rolf Eliassen
Project Director

Stanford University
Stanford, California

Covering the Period
September 15, 1962 to July 15, 1963

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SUMMARY

Laboratory studies are well along on this project. By the use of either of the most promising coagulants, liquid alum or ferric sulfate, phosphorus can be reduced to a low concentration. The removal of nitrogen by a denitrification process has not been successful as yet. Over 50% of the ABS and a significant portion of the COD has been removed by a foaming process. Some success in disposing of the foam by returning it to the activated sludge unit has been achieved, but results are not conclusive on this point. A study of the mixing characteristics of the laboratory activated sludge model was done.

By the use of a strong base ion exchange resin, it is possible to remove phosphates, nitrates, nitrites and ABS, and reduce COD in one operation. By using sea water as the regenerant, costs can be kept down. One problem is the large increase in chloride content. Work is continuing on the use of other resins and in different methods of regeneration.

A pilot scale model is now being set up at the Palo Alto Sewage Treatment Plant for tests of the different methods on a larger scale and for demonstration to the public.

STATEMENT OF PROGRESS

The objective of this project is to demonstrate the feasibility of using tertiary and advanced treatment techniques in the reclamation of water from sewage. There exists at Palo Alto, California, a unique opportunity to do this. An ample supply of treated sewage exists at Palo Alto, which could be reclaimed and pumped to Stanford University, which is short of water. The reclaimed water could be put into Lake Lagunitas on campus and used for recharge to ground water supplies, irrigation and recreational uses. In order to do this, water of high quality would have to be produced, approaching drinking water standards. In addition, either nitrogen, phosphorus, or both, would have to be removed in order to limit the growth of algae in the lake itself.

The program is being approached in three phases. The first phase consists of laboratory studies to be used as the basis for the second phase, construction of a pilot scale model at the Palo Alto Sewage Treatment Plant. The third phase would be the full-scale water reclamation plant to provide re-usable water for Stanford. The current study, supported by the Public Health Service, includes phases 1 and 2.

Laboratory Program

For the laboratory studies a model 2.5 liter activated sludge unit has been built. It has a separate settling tank and utilizes a B.I.F. diaphragm pump to return the settled sludge to the mixed liquor compartment. Raw sewage is fed at a rate of 7 milliliters per minute, giving a detention time of approximately six hours. Good quality effluent has always been available from this unit for further processing.

The following operations have been considered for polishing this effluent:

Removal of phosphorus by chemical coagulation;

Removal of nitrogen by denitrification of nitrates and nitrites to nitrogen gas;

Removal of ABS by foaming;

Removal of phosphorus, nitrogen and ABS by an ion exchange process.

In addition to tests for phosphorus, nitrogen and ABS, the influence of all the above processes on BOD, COD, suspended solids, and chlorides removal was studied. Also, the use of activated carbon for the removal of ABS and other undegradable organics will be studied.

Chemical Precipitation

Chemical precipitation for phosphorus removal was evaluated using conventional jar tests. The coagulant was added to the activated sludge effluent in 1 liter beakers. After an initial mix, coagulation was performed at 30 rpm for 10 minutes and the mixture allowed to settle for one hour.

The following coagulants were tried:

Lime
Laboratory Alum
Commercial Alum (liquid)
Ferrous Sulfate
Ferric Chloride
Commercial Ferric Sulfate
Separan (Dow Chemical Company)

Liquid alum and industrial ferric sulfate appeared to be the most promising of the coagulants. Results of studies with laboratory alum, liquid alum and industrial ferric sulfate are summarized in Figures 1, 2 and 3, respectively. As can be seen, pH was adjusted to several different values using lime. The variation in results at different pH values is perhaps partially due to variations in the phosphorus content of the treated sewage used. To smooth out these variations, all results were averaged and the results shown in Figure 4.

The difference between laboratory alum and liquid alum is partially the results of the method of computation. The laboratory alum concentration was based on pure alum, $Al_2(SO_4)_3$ with no water of hydration. For liquid alum the dose was based on the formula $Al_2(SO_4)_3 \cdot 14.3H_2O$, which is similar to the composition of commercial alum. When corrected to the same basis, removals were similar but removals were better with liquid alum, particularly at high doses.

Lime alone did not reduce phosphates to low levels. Ferric chloride, while removing phosphates, raised the chloride level excessively and was not considered further for that reason.

Ferrous sulfate removed phosphates when the pH was raised to 10 and above. This took large quantities of lime and resulted in excessively high pH values.

Separan is a coagulation aid. When used with alum, it seemed to aid phosphate removals at low concentrations, but not at high concentrations. Used by itself, it did not promote the removal of phosphates.

Liquid alum and industrial ferric sulfate were both effective in removing phosphates. Ferric sulfate had a tendency to introduce color, particularly at low pH. The cost of ferric sulfate in commercial quantities in the Palo Alto area at the present time is about $53 per ton. Liquid alum costs about $47 per ton based on weight of equivalent dry alum. Figure 5 is a comparison of chemical costs for phosphorus removal. From this, it appears that liquid alum and ferric sulfate are about equally good.

If it should be necessary to remove phosphates to a level of 0.18 mg/l as phosphorus, for example, chemical costs would be as follows:

	$ Acre-foot	$ Million Gallons	Cents/1000 gal
Liquid Alum	21.90	66.90	6.7
Ferric Sulfate	26.10	79.70	8.0

Denitrification

An attempt was made to remove nitrogen by a denitrification process similar to that described by Ludzack and Ettinger.[4] Certain bacteria are able to utilize oxygen obtained from nitrates and nitrites in the absence of dissolved oxygen. In order to take advantage of this, bacteria

[4] "Controlling Operation to Minimize Activated Sludge Effluent Nitrogen," Journal Water Pollution Control Federation, Vol. 34, No. 9, September 1962, p. 920.

in the mixed liquor of the activated sludge are allowed to come in contact with raw sewage in the absence of air in a separate chamber of the aeration compartment. If well nitrified activated sludge is available, denitrifying bacteria will utilize oxygen from the nitrates and nitrites and liberate nitrogen as a gas.

These attempts so far have met with only sporadic and very limited success. In order to maintain this second compartment, it is necessary to provide mixing. The only mixer available was difficult to control at low speeds. Evidently the mixer broke up the floc, which hindered settling. Each time the denitrification process was tried, the activated sludge suffered an upset. It may be also that the anaerobic compartment had a deterimental effect on the activated sludge process itself.

Another possible reason for lack of success in this part of the study was the lack of sufficient time to give close attention to the equipment and run the continuous tests required. Another mixer is being fabricated and work on this part of the study is continuing.

Foam Fractionation

ABS has been removed from the activated sludge effluent by the foaming process. The foamer used was obtained from the California Research Corporation in Richmond, California. The foamer volume is 80 ml, which gives a residence time of about 11-1/2 minutes in the foamer. No attempt was made to measure the air used. Air was simply adjusted so that foam was produced and liquid was not bubbled out of the unit.

The foam fractionation study has proceeded in three parts to date. First, the foam was collected in a separate flask for disposal. The principle drawback with this might be the difficulty in disposing of the collected foam. However, California Research has had success in degradation of ABS by recycling the foam back to the activated sludge unit. This method of foam disposal was tried in the second part of our study. In the third part the flow was split so that only half the flow went through the foamer. The foam removed here also was returned to the mixed liquor compartment of the activated sludge unit.

Foam fractionation results have been averaged and are shown in the following table:

TABLE I

		ABS CONCENTRATION mg/l		
			Activated Sludge Effluent	
		Raw Sewage	Before Foamer	After Foamer
Phase I	Foam collected	5.28	2.56	1.04
Phase II	Foam returned to activated sludge unit	3.83	3.24	0.98
Phase III	One-half flow thru foamer. Foam returned to activated sludge unit	3.37	2.07	0.87

Results indicate that with the foamer used (which is probably somewhat undersized) considerably more than one-half of the effluent ABS was removed. It is difficult to compare results in the three phases because of the differences in the ABS concentration in the raw sewage, but apparently returning the ABS to the activated sludge unit had an adverse effect on ABS removal in the activated sludge .

The foamer was also effective in removing COD. Results have been averaged and are shown in Table II:

TABLE II

		COD mg/l Activated Sludge Effluent		
		Before Foamer	After Foamer	Percent Removal
Part I	Foam collected	88	66	25
Part II	Foam returned to activated sludge unit	107	67	37
Part III	One-half flow thru foamer, foam returned to activated sludge unit	94	58	38

Ion Exchange

A strong base resin (Duolite A-102D) was used to remove phosphorus, nitrogen and ABS. The resin was regenerated with sea water. No attempt was made to run the resin to exhaustion. Results of a number of runs are as follows:

TABLE III

ALL QUANTITIES mg/l

	Phosphates as P	Nitrates as N	Nitrites as N	ABS	COD	Chlorides
Influent	2.8	8.4	7.6	1.4	40	179
Effluent	0.16	0.69	0.25	0.17	20	370
% Removal	94	92	97	88	50	---
% Increase	- -	- -	- -	- -	- -	52

Studies using this and other resins are continuing.

For most of the results summarized above, an extremely short column length was used. Therefore, much better removals than shown above may be possible.

Anions such as phosphates and nitrates are exchanged for chlorides, and can be removed by sea water regeneration. ABS and other organics, however, are adsorbed on the resin and cannot be removed in this way. Unless some method for removing these complex organics can be found, the spent resin may have to be thrown away. This may not be too bad as the resins have a large capacity for these organics and can still be regenerated in the normal manner to remove the inorganic anions.

Activated Sludge Mixing Evaluation

An experiment was devised to evaluate the mixing characteristics of the laboratory model activated sludge unit. This determination was done early in the project and the configuration of the activated sludge unit has since been changed. The principal benefits derived from the conduct of this experiment included an evaluation of the activated sludge process, and perfecting the technique for later use on the pilot scale model.

At the time this experiment was done, the activated sludge unit had a volume of approximately 2.3 liters, including a denitrification chamber and a settling chamber. Flow was 7 ml/min, giving a detention time of approximately 5-1/2 hours.

Radioactive Na^{24}, produced in the Stanford Nuclear Reactor, was introduced into the system at the raw sewage influent point. Samples of effluent were collected periodically and counted, using a single channel gamma ray spectometer.

The results are shown in Figure 6. The flow rate did not hold steady during the experiment, which accounts for the changes in slope of the curve. Theoretical lines based on the actual flow closely paralleled the plotted curve. Very briefly, conclusions were as follows:

1. The time for the first material to pass through the system was about 10 minutes.
2. Complete mixing took about 1 hour.
3. The time for 98% of the material to pass out of the system after complete mixing was about 23 hours.
4. The flow-through system is governed by a first order equation.
5. Sodium^{24} is a very satisfactory material to use in a flow evaluation.

PILOT PLANT PROGRAM

Phase 2, the Pilot Plant Program, is just beginning. The first unit, a 10 gpm activated sludge unit is now in operation. This unit is owned and presently operated by the Chicago Pump Company. It will be available for use for the duration of the project.

The second unit, for chemical treatment, has been fabricated by Infilco and at the present time is being shipped to Palo Alto. This unit also includes a sand filter.

Other units are in the planning stage and will be added from time to time. A diatomaceous earth filter built by the De Laval Turbine Pacific Company will be made available for use, as will other units. A small pond will be provided on the treatment plant site, to indicate the quality of effluent being produced. Also, it will offer an opportunity to check for the possible growth of algae in the reclaimed water.

DEMONSTRATION PLAN

The laboratory program is being carried forth substantially as presented in the original Application. The program is described elsewhere in this report.

The pilot plant program is proceeding as presented in the original Application, except for the fact that all equipment is being donated by the equipment companys. This is so for two reasons, lack of funds and the availability of suitable equipment.

Work is not yet complete in establishing the flow sheet for the pilot plant phase; however, at this point it appears that there will be two alternates as follows:

1. a. Activated Sludge Sewage Treatment
   b. Denitrification
   c. Foam Fractionation for ABS Removal
   d. Chemical Coagulation
   e. Filtration
   f. Chlorination

2. a. Activated Sludge Sewage Treatment
   b. Filtration
   c. Ion Exchange
   d. pH Adjustment
   e. Chlorination

PROFESSIONAL STAFF

1. Project Director -- Dr. Rolf Eliassen

   Professor of Civil Engineering, Stanford University.

   Professor Eliassen has been with the project since its inception and has spent about 10% of his time on the project. Biographical data was included in the original Application.

2. Dr. Perry L. McCarty

   Associate Professor of Civil Engineering, Stanford University.

   Professor McCarty has been with the project since its inception and has spent about 10% of his time on the project. Biographical data was included in the original Application.

3. Bruce M. Wyckoff

   Research Engineer, Stanford University.

   Mr. Wyckoff has been with the project since October 15, 1962, and has spent 100% of his time on the project.

   Education: B. S. in Civil Engineering, 1950, Stanford University.
   Completed requirements for M.S. degree to be awarded in September, 1963, Stanford University.

   Registered Civil Engineer, California.

   Experience: Paul L. Adamson, Consulting Civil Engineer, Palo Alto, California, 1956 - 1962.
   Worked as a Civil Engineer in Sanitary Engineering and General Civil Engineering. Work included planning, design and field supervision of water supply, sewerage, flood control and sewage treatment works.
   City of Redwood City, Engineering Department, 1954 - 1955.
   California Water Service Company, 1953.
   U. S. Geological Survey, Water Resources Division, 1950, 1953

4. Walter Francis Rowland

Acting Instructor and Research Assistant

Mr. Rowland has been with the project since March 1, 1963, and has spent 100% of his time on the project.

Education:

Millikin University (Civil Engineering),		1949 - 1952
University of Illinois (with high honors)	B.S.	1954
University of Illinois	M.S.	1958
Stanford University (Doctoral candidate in CE)		1959 - Date

Experience:

Illinois Division of Highways, Springfield, Illinois, Civil Engineering Aide, Summers 1951, 1952, 1953 and 1954.

Chief of Battalion Survey, 246th FAM Bn., U.S. Army, Fort Bliss, Texas 1954-56

University of Illinois, Department of Civil Engineering, Instructor 1957

Clark, Daily and Dietz, Consulting Engineers, Urbana, Illinois, Sanitary Engineer Summer, 1957

Stanford University, Department of Civil Engineering, Acting Instructor and Research Assistant, 1961 to the present.

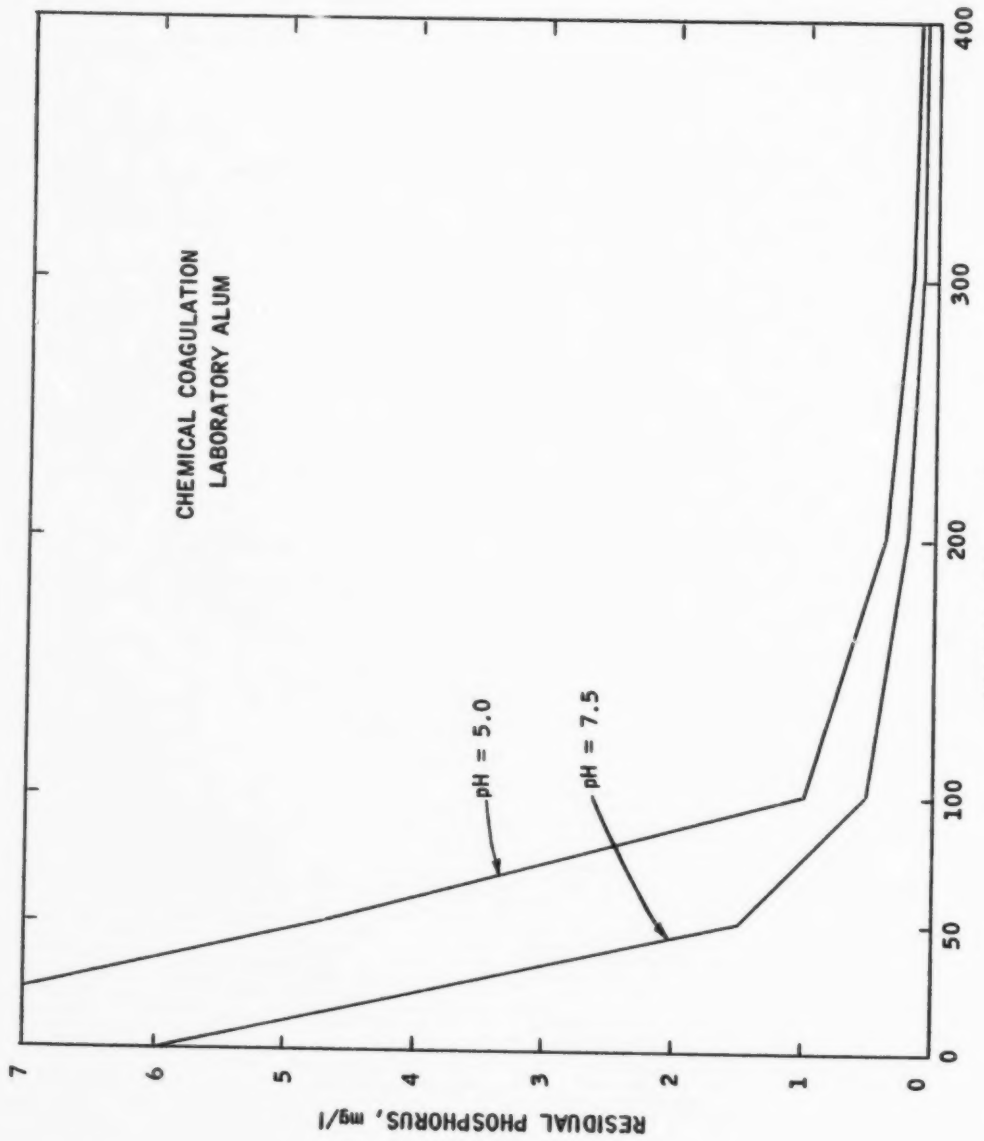
CHEMICAL COAGULATION
LABORATORY ALUM
pH = 5.0
pH = 7.5
RESIDUAL PHOSPHORUS, mg/l
CHEMICAL DOSE, mg/l
0
1
2
3
4
5
6
7
0
50
100
200
300
400

Figure 1

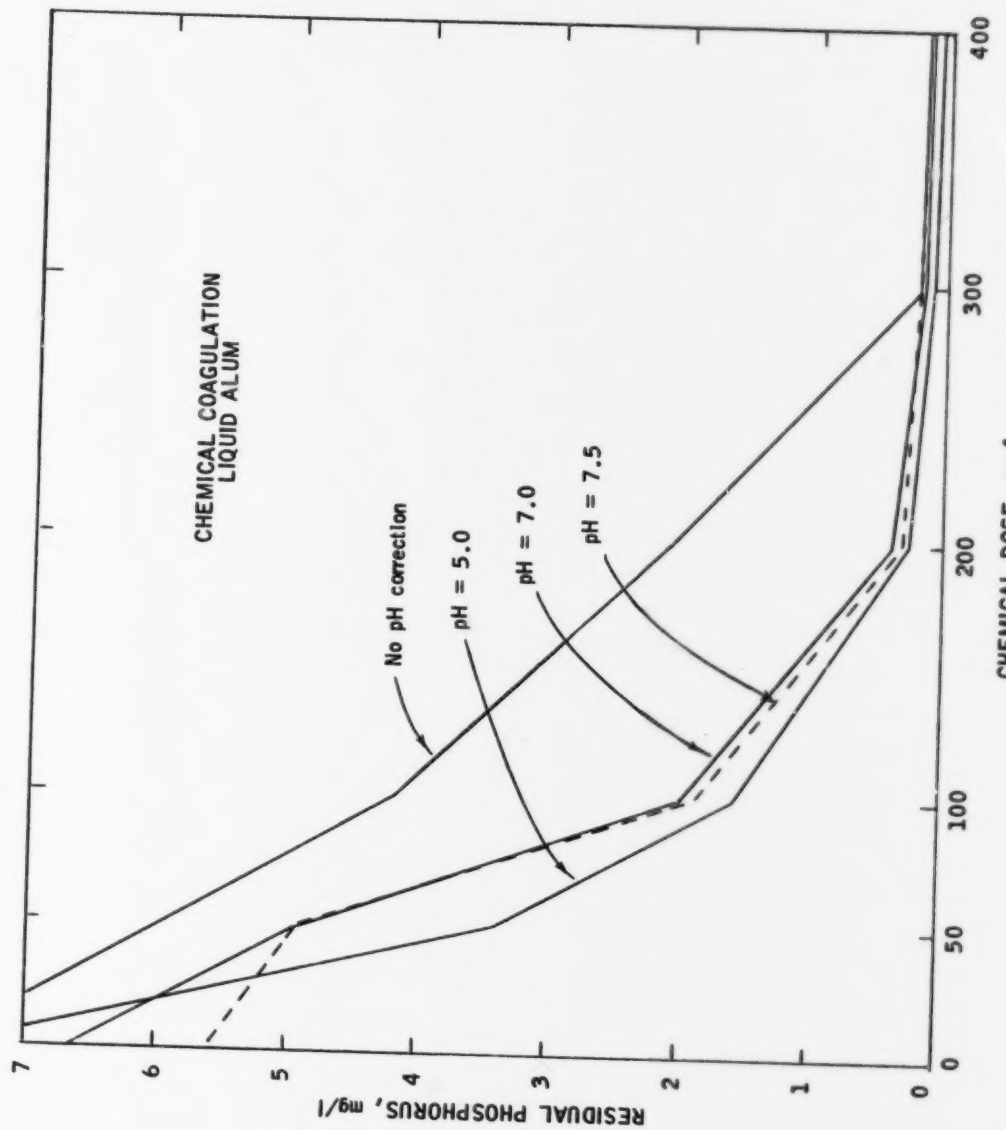
CHEMICAL COAGULATION
LIQUID ALUM
No pH correction
pH = 5.0
pH = 7.0
pH = 7.5
RESIDUAL PHOSPHORUS, mg/l
CHEMICAL DOSE, mg/l
0
1
2
3
4
5
6
7
0
50
100
200
300
400

Figure 2

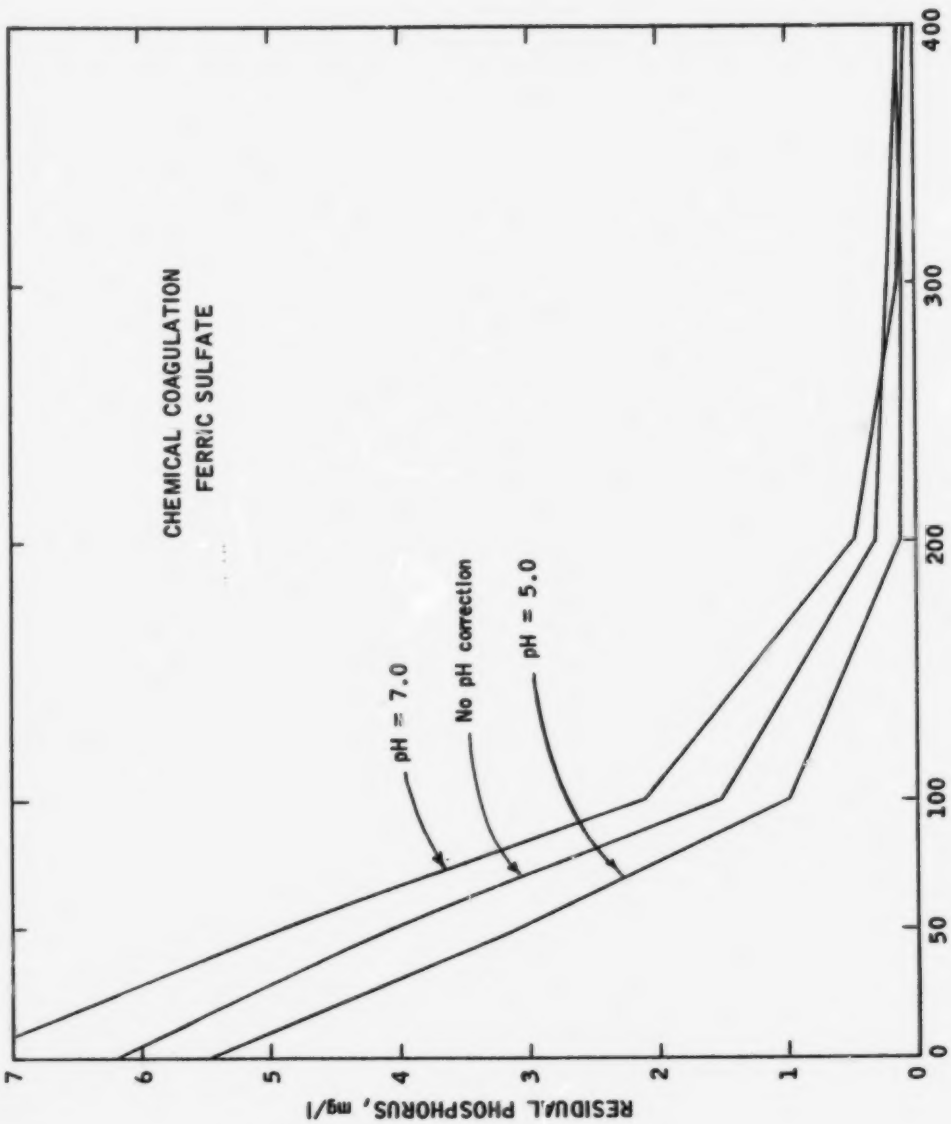
CHEMICAL COAGULATION
FERRIC SULFATE
pH = 7.0
No pH correction
pH = 5.0
RESIDUAL PHOSPHORUS, mg/l
CHEMICAL DOSE, mg/l
0
1
2
3
4
5
6
7
0
50
100
200
300
400

Figure 3

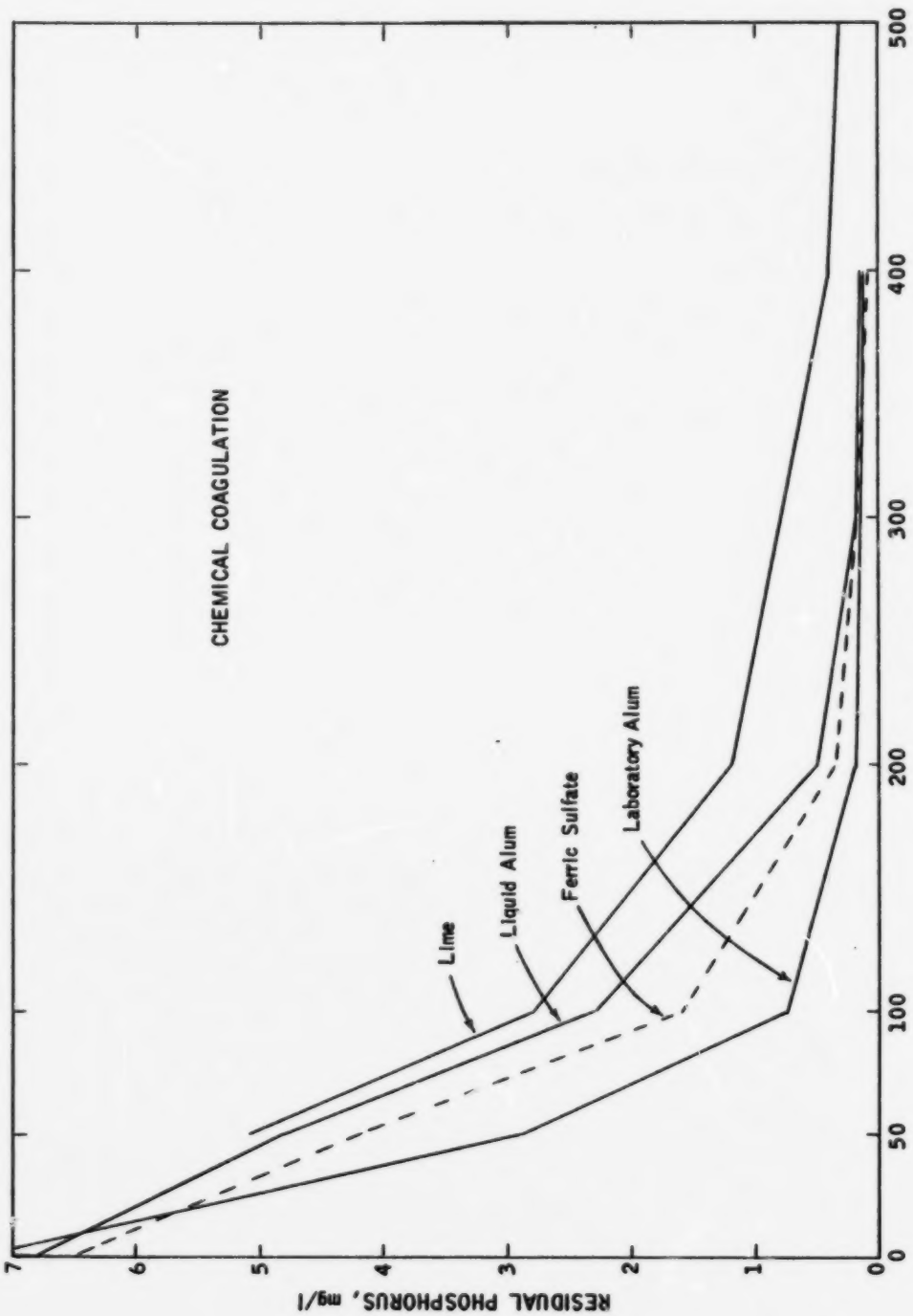
CHEMICAL COAGULATION
Lime
Liquid Alum
Ferric Sulfate
Laboratory Alum
RESIDUAL PHOSPHORUS, mg/l
CHEMICAL DOSE, mg/l
0
1
2
3
4
5
6
7
0
50
100
200
300
400
500

Figure 4

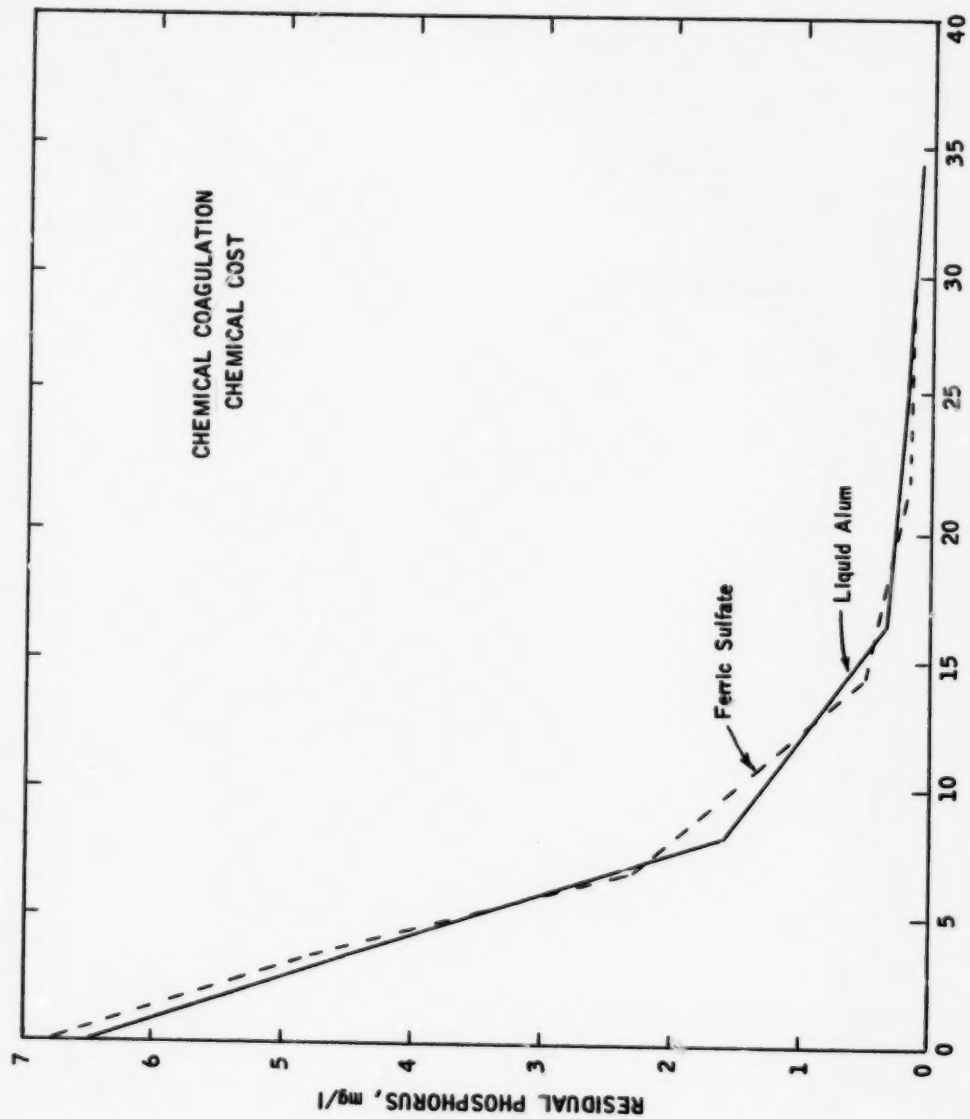
CHEMICAL COAGULATION
CHEMICAL COST
Ferric Sulfate
Liquid Alum
RESIDUAL PHOSPHORUS, mg/l
CHEMICAL COST, DOLLARS/ACRE-FOOT
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
35
40

Figure 5

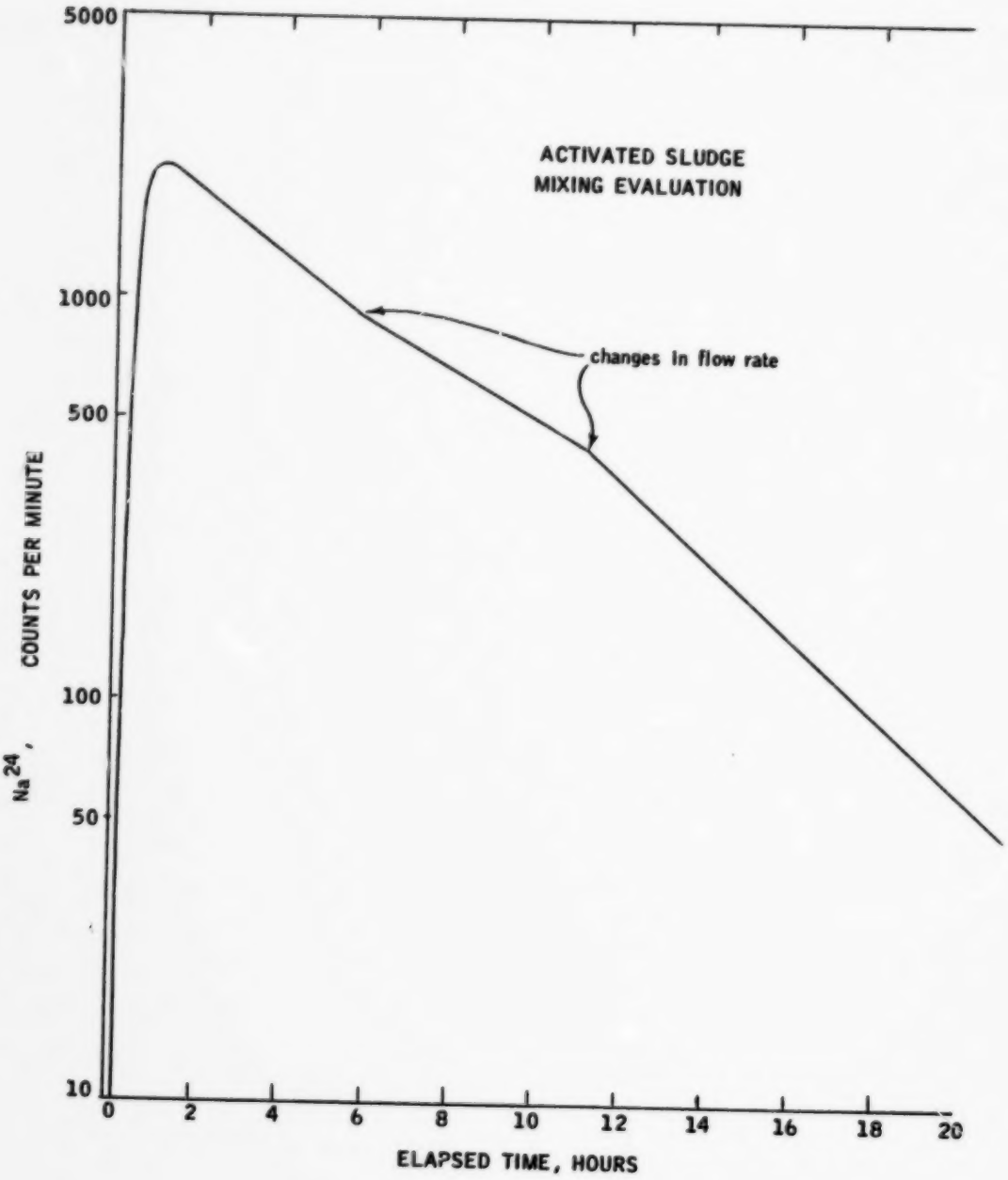
ACTIVATED SLUDGE
MIXING EVALUATION
changes in flow rate
5000
1000
500
100
50
10
Na^{24}, COUNTS PER MINUTE
0
2
4
6
8
10
12
14
16
18
20
ELAPSED TIME, HOURS

Figure 6